

AD-A085 734

ARMY ELECTRONICS RESEARCH AND DEVELOPMENT COMMAND WS--ETC F/G 4/2
BINOMIAL SIZE DISTRIBUTION MODELS FOR F06S AT HEPPEN, GERMANY. (U)
APR 80 L D DUCAN, R D LOW

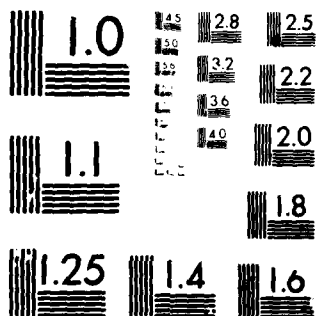
UNCLASSIFIED

ERADCOM/ASL-TR-0056

NL

1 of 1
AD-A085 734

END
DATE
FILMED
7-80
DTIC



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

ASL-TR-0056

LEVEL

AD

Reports Control Symbol
OSD-1366

**BIMODAL SIZE DISTRIBUTION MODELS
FOR
FOGS AT MEPPEN, GERMANY**

APRIL 1980

By

**LOUIS D. DUNCAN
RICHARD D. H. LOW**

DTIC
EXTRACTED
JUN 18 1980

Approved for public release; distribution unlimited



**US Army Electronics Research and Development Command
ATMOSPHERIC SCIENCES LABORATORY
White Sands Missile Range, NM 88002**

80 6 17 003

ADA 085734

NOTICES

Disclaimers

The findings in this report are not to be construed as an official Department of the Army position, unless so designated by other authorized documents.

The citation of trade names and names of manufacturers in this report is not to be construed as official Government indorsement or approval of commercial products or services referenced herein.

Disposition

Destroy this report when it is no longer needed. Do not return it to the originator.

ERRATA FOR ASL-TR-0056

BIMODAL SIZE DISTRIBUTION MODELS FOR FOGS

AT MEPPEN, GERMANY

Page 9 Change equation (1) as follows:

$$K_{\lambda} = \pi \int_{r_1}^{r_2} r^2 n(r) Q_{\text{ext}}(m, r, \lambda) dr , \quad (1)$$

Change equation (2) as follows:

$$W = \frac{4}{3} \pi \int_{r_1}^{r_2} r^3 n(r) dr , \quad (2)$$

Page 11 Equation (3). Change numerator from r^{α} to r^{α}

Equation (5), last line:

$$(\alpha + 2) \cdots (\alpha + n) .$$

Page 14 Fourth paragraph, last line:
of (5) to solve for β

Page 21 Table 3, 6th column:
Change K'_{10} to K_{10}

14 ERADCOM/ASL-TR-0056

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER ASL-TR-0056	2. GOVT ACCESSION NO. AD-A095734	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) BIMODAL SIZE DISTRIBUTION MODELS FOR FOGS AT MEPPEN, GERMANY		5. TYPE OF REPORT & PERIOD COVERED R&D Technical Report
7. AUTHOR(s) Louis D. Duncan Richard D. H. Low		6. PERFORMING ORG. REPORT NUMBER Feb-Mar 78
9. PERFORMING ORGANIZATION NAME AND ADDRESS Atmospheric Sciences Laboratory White Sands Missile Range, New Mexico 88002		8. CONTRACT OR GRANT NUMBER(s) 1244
11. CONTROLLING OFFICE NAME AND ADDRESS US Army Electronics Research and Development Command Adelphi, MD 20783		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS DA Task 11L62111AH71
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		12. REPORT DATE April 1980
		13. NUMBER OF PAGES 24
		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE
16. DISTRIBUTION STATEMENT (of this Report) Approved for public release; distribution unlimited.		
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)		
18. SUPPLEMENTARY NOTES		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) Fog microphysics Optical extinction Liquid water content Gamma function		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) Models have been fitted to fog data collected at Meppen, Federal Republic of Germany, during February and March 1978. These models are formulated as the sum of two gamma distributions in order to preserve the basic shape characteristics of the observed size distributions--in particular, their bimodal characteristics. The models accept visibility as an input and generate a size distribution consistent with this input.		

DTIC
ELECTE
JUN 18 1980
S C D

DD FORM 1 JAN 73 1473

EDITION OF 1 NOV 65 IS OBSOLETE

1

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

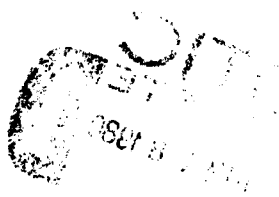
410663

JOB

20. ABSTRACT (cont)

Six parameters are required to determine a model size distribution. It is shown that constants can be assigned to two of these parameters. Algorithms, based upon curve fits, are developed for computing the other parameters as a function of visibility.

Tables and graphs are presented which demonstrate the capability of the model to reproduce the features of the measured drop-size distributions; also included are comparisons of the derived quantities of liquid water content and infrared extinction coefficients.



CONTENTS

INTRODUCTION.....	5
BACKGROUND.....	6
DATA USED FOR MODEL DEVELOPMENT.....	8
Fitting the Bimodal Gamma Distribution.....	11
Evaluation of Model Outputs.....	16
Concluding Remarks and Some Observations.....	20
REFERENCES.....	23

Accession For	
NTIS GRA&I	<input checked="checked" type="checkbox"/>
DDC TAB	
Unannounced Justification	
By _____	
Distribution/	
Availability Codes	
Dist.	Avail and/or special
A	

INTRODUCTION

Over the next few years, various kinds of thermal imaging and other electro-optical sensing devices will be developed and deployed as integral components of diverse types of military and civilian systems. Under limited visibility conditions, the performance of such systems may be adversely affected. The point at which this degradation becomes significant depends upon a number of factors such as the intended application, the nature of low visibility conditions, and the system itself. Both the designer and the user should be aware of the environmental limitations and should possess the tools for an assessment of the severity of these limitations. The purpose of this report is to attempt to provide such tools.

Dense haze or fog occurrences in the lower atmosphere produce sharp reduction in visibility which may persist for hours. The resulting attenuation of the electromagnetic radiation by the suspended haze and/or fog particles depends upon their number concentration, refractive index, and characteristics of the size distribution. The extinction (or conversely, transmission) property of this polydispersion is highly wavelength dependent from the visible through the infrared; such dependence appears to be strongly related to the size range as well as the shape of the size distribution.

In the past, the drop-size data found in the literature were collected, almost without exception, with mechanical impactors and reduced with the aid of a microscope.¹ The collection efficiency of these impactors drops to nearly zero for particles of $1\mu\text{m}$ to $2\mu\text{m}$ radius. While the tiny particles less than $1\mu\text{m}$ to $2\mu\text{m}$ radius may play an insignificant role in the microphysics and dynamics of cloud/fog formation, growth, and dissipation, they cannot be lightly neglected in the optics of a hazy/foggy environment. Their importance has been demonstrated by Hindman and Heimdahl.² As a result of missing the tiny particles, the drop-size spectra on the average often revealed a unimodal distribution. Past efforts in modeling a distribution of this type have been made by resorting to standard statistical functions³ without regard to optical implications of the distribution. However, with the advent of optical particle counters and the resulting finer resolution, the drop-size

¹B. J. Mason, 1971, The Physics of Clouds, Oxford University Press, 617 pages

²E. E. Hindman II and O. E. R. Heimdahl, 1977, "Submicron Haze Droplets and their Influence on Visibility in Fog," preprint, 6th Conference Inadvertent and Planned Weather Modification, Am Meteorol Soc, Boston, MA, 10-13

³N. H. Fletcher, 1962, The Physics of Rainclouds, Cambridge University Press, 386 pages

spectra on the average often do not appear to be unimodal, but unmistakably reveal a second mode in what Hindman and Heimdahl² called the haze regime.

During the past several years, a significant amount of drop-size data has been collected by the NATO countries and the United States in an effort to establish a data base for the evaluation of various types of military electro-optical systems. An analysis of these data shows that the drop-size distributions on the average are usually bimodal and their shapes vary considerably with variations in visibility (e.g., Low³). With these characteristics in mind, we have undertaken to further analyze these data and to develop more adequate haze/fog models, which are bimodal in shape and which reflect the changes in drop-size spectra with visibilities. This report represents the initial results of these investigations. In the following section, a review of the state of the art in fog modeling together with a set of criteria for the formulation of models will be presented. Next, the nature of the data used and the steps in model development are discussed. This discussion is then followed by an evaluation of model outputs and our concluding remarks in two separate sections.

BACKGROUND

Two skewed probability density functions have most often been used in the past to model haze/fog drop-size spectra, i.e., lognormal and gamma.^{3, 5, 1} There are, then, two variations of the gamma function.^{7, 8}

²E. E. Hindman II and O. E. R. Heimdahl, 1977, "Submicron Haze Droplets and their Influence on Visibility in Fog," preprint, 6th Conference Inadvertent and Planned Weather Modification, Am Meteorol Soc, Boston, MA, 10-13

³R. D. H. Low, L. D. Duncan, and Y. Y. R. Hsiao, 1979, Microphysical and Optical Properties of California Coastal Fogs at Fort Ord, ASL-TR-0034, US Army Atmospheric Sciences Laboratory, White Sands Missile Range, NM, 22 pages

⁵N. H. Fletcher, 1962, The Physics of Rainclouds, Cambridge University Press, 386 pages

⁷A. Kh. Khrgian, Ed., 1963, Cloud Physics, Israel Program for Scientific Translations, Jerusalem, 392 pages

¹B. J. Mason, 1971, The Physics of Clouds, Oxford University Press, 617 pages

⁷A. Kh. Khrgian and I. P. Mazin, 1952, "Distribution of Drops According to Size in Clouds," Trudy Tsen Aero Obs, 7:56-61 (English version)

⁸D. Deirmendjian, 1964, "Scattering and Polarization Properties of Water Clouds and Hazes in the Visible and Infrared," Appl Opt, 3:187-196

Of the two, the former reduced the two parameters of the function to one, and the latter added one parameter to make it a three-parameter function. Following Diermendjian's lead, Tampieri and Tomasi⁹ assembled a large amount of fog data from the literature and developed statistical models on the basis of these data. Their results show that there can be appreciable variations among fog drop-size spectra resulting from different formation processes. It may be of some historical interest to note that according to Khrgian,⁵ Levin⁶ first suggested in 1958 that the size distribution of droplets obeys the lognormal law discovered by Kolmogorov for the size of gold particles in placer deposits, but then finally settled on the gamma distribution (1958) on the basis of cloud-chamber experiments. Each function will undoubtedly have its adherents. According to Twomey,¹⁰ there appear to be no theoretical grounds for stating that haze/fog spectra should necessarily follow any or all of these distribution functions (or any other for that matter), and the problem is largely one of curve fitting.

After having examined a large set of drop-size spectra, Zevu¹¹ felt that most samples could be adequately approximated by a gamma distribution. When one inspects a large number of sample distributions as we have done, it becomes immediately apparent that no simple distribution function can reproduce all of the features exhibited by measurements. Nor is it evident that such detailed representation is necessary or desirable, considering the state of the art in aerosol sampling. In fact, having compared a number of different optical particle counters in a carefully designed laboratory investigation, Cross and Fenn,¹² showed

⁹F. Tampieri and C. Tomasi, 1976, "Size Distribution Models of Fog and Cloud Droplets in Terms of the Modified Gamma Function," Tellus, 28:333-347

⁵A. Kh. Khrgian, Ed., 1963, Cloud Physics, Israel Program for Scientific Translations, Jerusalem, 392 pages

⁶L. M. Levin, 1958, "Functions to Represent Drop-size Distributions in Clouds," Izv Geofiz Ser, 10:1211-1221 (English version)

¹⁰S. Twomey, 1977, Atmospheric Aerosols, Elsevier, NY, 302 pages

¹¹V. E. Zevu, 1970, Atmospheric Transparency in the Visible and in the Infrared, Israel Program for Scientific Translations, Jerusalem, 220 pages

¹²T. S. Cross and R. W. Fenn, Ed., 1978, OPAQUE Aerosol Counter Intercomparison, 25 April 1977--4 May 1977, AFGL-TR-78-0004, USAF Geophysics Laboratory, Hanscom AFB, MA, 56 pages

that the optical devices in current use for measuring drop-size distributions are accurate to within a factor of 2. Since the observed drop-size data are typically bimodal, it would be logical to formulate bimodal distribution functions to represent them. Of the two commonly used density functions, the gamma function is simpler to handle and its various moments can be readily generated. The bimodal feature may be easily represented by the weighted sum of the two gamma distributions.

Since there is no theoretical reason for selecting a priori a particular type of model, a set of guidelines by which the models are to be developed must be established. The guidelines are as follows:

1. The model should be as simple as practicable.
2. The model should reproduce, well within a factor of 2, the data and the derived quantities such as liquid water content and infrared extinction coefficients.
3. The fitting of the model to the measured data should not be an onerous task.

Following these guidelines, the lognormal distribution, the one-parameter gamma distribution of Khrgian and Mazin,⁷ the standard two-parameter gamma distribution, and the three-parameter distribution of Deirmendjian⁸ in two modes were each fitted to the same sets of data and carefully analyzed. The lognormal distribution gave rather inconsistent results, the one-parameter gamma distribution was consistent but not accurate enough, and the three-parameter gamma distribution was superior to either of the above, but not enough over the two-parameter gamma distribution to warrant the added burden of carrying an extra parameter. Therefore, the bimodal two-parameter gamma distribution was elected.

DATA USED FOR MODEL DEVELOPMENT

The data used for developing and fitting the model were obtained by the Atmospheric Sciences Laboratory (ASL) during an extensive field experiment at Meppen, Germany.* Ground-based measurements of haze/fog

⁷A. Kh. Khrgian and I. P. Mazin, 1952, "Distribution of Drops According to Size in Clouds," Trudy Tsen Aero Obs, 7:56-61 (English version)

⁸D. Deirmendjian, 1964, "Scattering and Polarization Properties of Water Clouds and Hazes in the Visible and Infrared," Appl Opt, 3:187-196

*A comprehensive technical report on the Meppen experiment is in preparation.

drop-size distributions were made with a Particle Measuring Systems FSSP-100 light scattering particle measurement device (commonly known as Knollenberg Counter) which measures drop sizes from 0.25 μ m to 23.5 μ m radius. The data from 22 February 1978 and 4 March 1978 were reduced to obtain an average size distribution every 5 minutes and were used for curve fitting. These two sets were chosen because of the large number of drop-size spectra collected (24 hours on 22 February and 16-1/2 hours on 4 March) as well as the broad range of visibilities encountered. Computed visibilities* ranged from 0.04 km to 2.7 km on 22 February and from 0.02 km to 7.5 km on 4 March.

In the course of analyzing this huge amount of data, we often noted that there was an apparent relationship between the ranges of visibility and the shape characteristics of a distribution. To display these characteristics, the visibility range was segmented and the mean size distributions for the various segments were computed. Mean size distributions for 22 February are shown in figure 1, and the mean size distributions for the 0- to 200-meter visibility segment for several days are shown in figure 2. Inspection of these two figures not only reveals the distinct bimodal character of the drop-size spectra but also shows that the most pronounced change with changing visibility in these spectra is manifest in the second mode.

The relative importance of the two modes can be investigated by employing some of the computations which are frequently used in assessing the degradation of an electro-optical system. These computations are liquid water content and extinction coefficient. The extinction coefficient, K_λ , at a wavelength λ is computed from

$$K_\lambda = \pi \int_{r_1}^{r_2} r^2 n(r) Q_{\text{ext}}(m, r, \lambda) dr, \quad (1)$$

where $n(r)$ is the size distribution; $Q_{\text{ext}}(m, r, \lambda)$ is the Mie extinction efficiency factor at complex refractive index m , radius r , and wavelength λ ; and r_1 and r_2 are the range of radii over which $n(r)$ is defined. Liquid water content W of the distribution is given by

$$W = \frac{4}{3} \pi \int_{r_1}^{r_2} r^3 n(r) dr, \quad (2)$$

*Throughout the paper, the values used for visibility were calculated from the drop-size distributions.

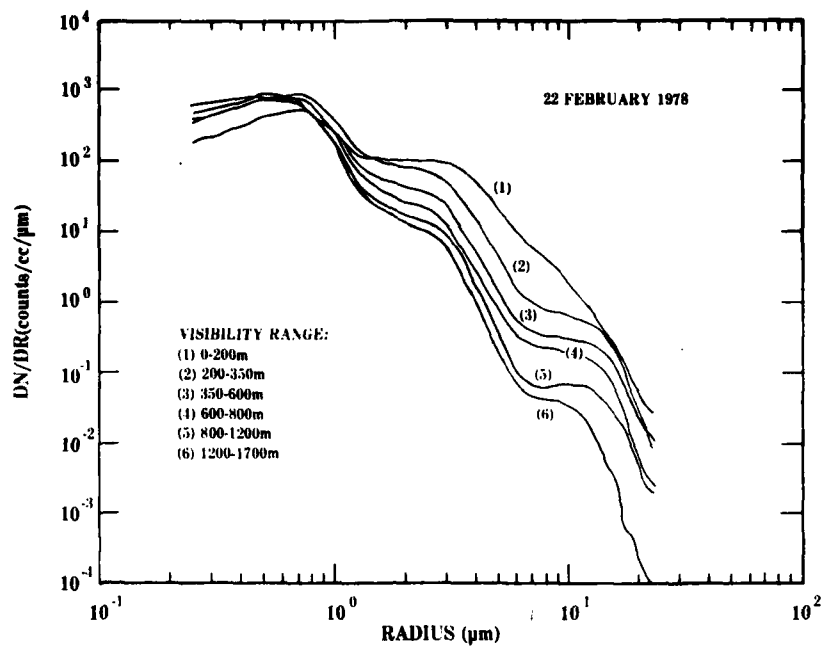


Figure 1. Mean drop-size distributions of the Meppen fog on 22 February 1978 corresponding to different visibility ranges.

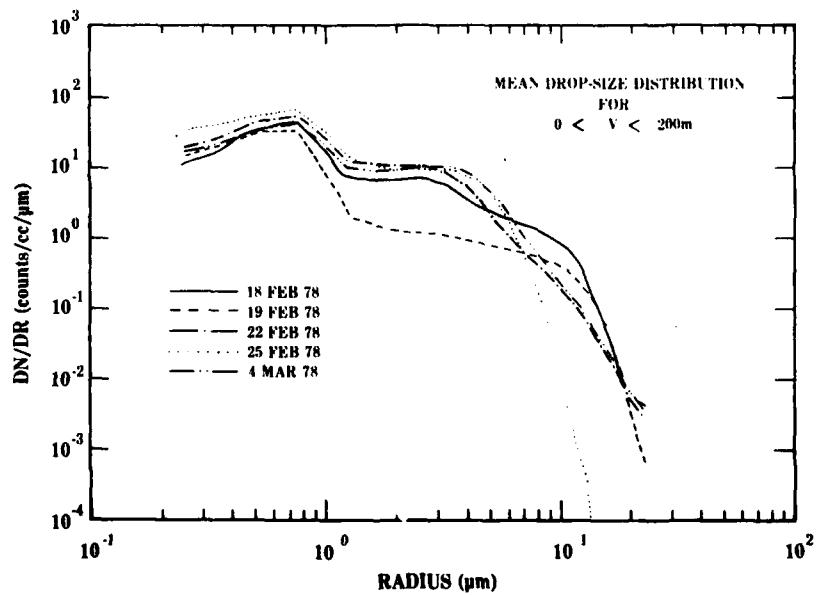


Figure 2. Mean drop-size distributions in the 0 m to 200 m visibility range on different foggy days at Meppen, Germany.

with the implicit assumption that the density (of liquid water) is unity. Now if we define $K_\lambda(r)$ to be the partial integral obtained by integrating equation (1) from r_1 to $r \leq r_2$ and let $P_1(r) = 100 k_\lambda(r)/K_\lambda$, then $P_1(r)$ is the percent of the total extinction at wavelength λ resulting from particles of sizes equal to or less than r . With a similar definition of $W(r)$ and $P_2(r)$, we have the percent of the total liquid water content up to radius r . Examples of such calculations are shown in figures 3 and 4 for visibilities of 1.95 and 0.258 km, respectively. The 10 and 90 percentile radii from a number of different visibility values are presented in table 1. These graphs show that the major contribution to both extinction and liquid water comes from the second mode of the distribution.

Fitting the Bimodal Gamma Distribution

The gamma distribution is defined by the density function

$$\Gamma(r, \alpha, \beta) = \frac{\alpha^\alpha}{\Gamma(\alpha)} \frac{r^{\alpha-1}}{\beta^\alpha} e^{-r/\beta} \quad (3)$$

where α and β are the two parameters subject to $\alpha = 1$ and $\beta > 0$. Published literature disagrees as to whether α is required to be an integer. Since restricting α to integer values simplifies the computations considerably, we decided to adopt this approach in our model development. The statistical moments as given by the equation

$$\mu_n(\alpha, \beta) = \int_0^\infty r^n \Gamma(r, \alpha, \beta) dr, \quad (4)$$

are

$$\begin{aligned} \mu_1(\alpha, \beta) &= \beta(\alpha + 1) \\ \mu_2(\alpha, \beta) &= \beta^2(\alpha + 1)(\alpha + 2) \\ \mu_n(\alpha, \beta) &= \beta^n(\alpha + 1)(\alpha + 2) \dots (\alpha + n). \end{aligned} \quad (5)$$

TABLE 1. TEN AND NINETY PERCENTILE RADII FOR COMPUTATION OF
LIQUID WATER CONTENT AND $10_{\mu m}$ EXTINCTION COEFFICIENT.
DATA IS FROM MEPPEN, GERMANY, 22 FEBRUARY 1978

Time	Visibility (km)	10th Percentile K_{10}	Lwc	90th Percentile K_{10}	Lwc
0005	1.95	0.75	0.6	12	9
0129	0.534	1.0	0.7	17.5	18.5
0216	0.407	3.5	3.0	15.0	15.0
0247	0.242	3.5	2.75	14.0	14.5
0334	1.08	1.8	1.0	14.0	14.0
0446	0.258	2.7	2.2	13.0	12.5
0527	0.172	3.0	2.5	12.0	12.0
0638	0.287	3.0	2.8	11.5	11.5
0751	0.173	3.0	2.5	12.5	12.5
0905	0.146	3.0	2.2	11.5	11.0
1018	0.529	2.6	2.0	14.5	15.0
1229	1.09	2.7	2.0	20.8	21.0
1358	0.304	3.2	2.9	17.5	18.0
1532	0.100	4.5	4.3	18.5	17.5
1626	0.090	4.6	4.5	18.0	19.0
2042	0.86	3.9	3.5	13.5	14.0
2200	0.112	3.9	3.5	10.5	10.5
2301	0.131	4.0	3.7	11.6	11.5

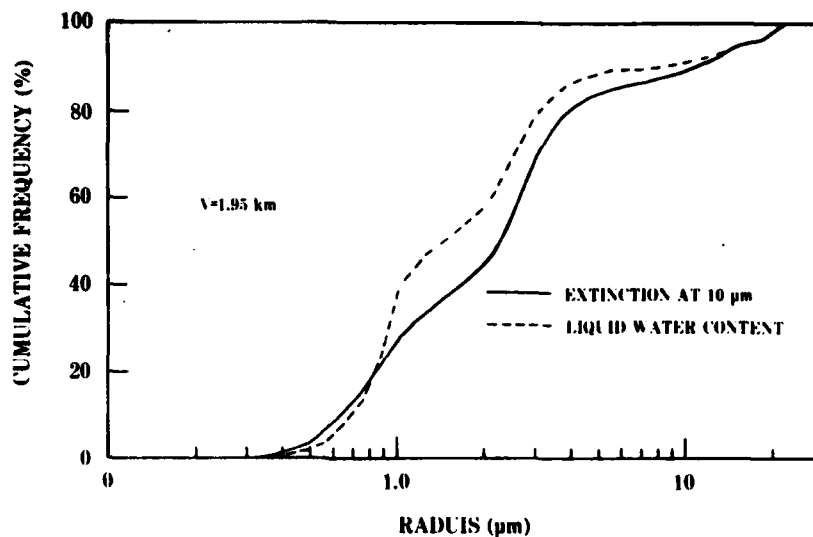


Figure 3. An example of cumulative frequency distributions of the liquid water content and the extinction coefficient at $10\mu\text{m}$ wavelength for visibility = 1.95 km. Note the relatively high percentage of sizes below the $1\mu\text{m}$ radius.

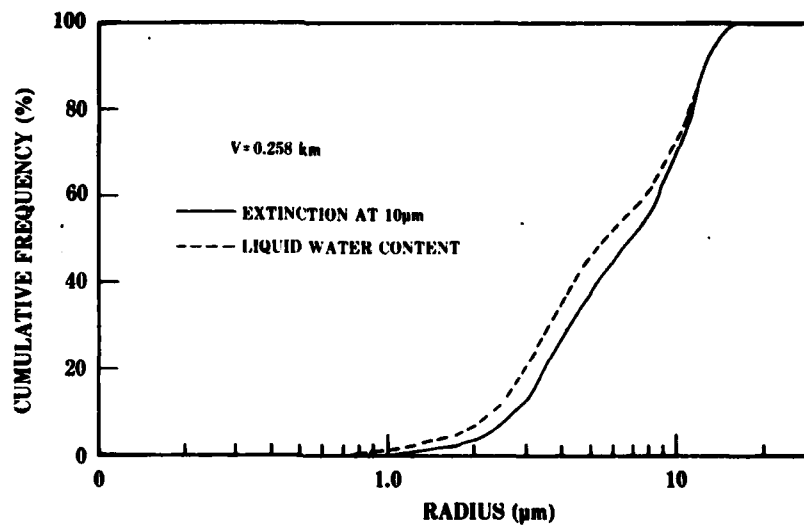


Figure 4. An example of cumulative frequency distributions of the liquid water content and the extinction coefficient at the $10\mu\text{m}$ wavelength for visibility = 0.258 km. Note the almost total absence of smaller droplets below $1\mu\text{m}$ radius.

The values of α and β are readily obtained from the first two moments,

$$\beta = \mu_2 / \mu_1 - \mu_1 \quad (6)$$

and

$$\alpha = \mu_1^2 / (\mu_2 - \mu_1^2) - 1. \quad (7)$$

As mentioned earlier, the data are typically bimodal and should be fitted with a bimodal function. In addition, equation (3) represents a density function, while the number concentration of a drop-size distribution is significantly greater than unity. This suggests a model of the form

$$n(r) = N_1 \Gamma(r, \alpha_1, \beta_1) + N_2 \Gamma(r, \alpha_2, \beta_2), \quad (8)$$

where N_1 , α_1 , β_1 , N_2 , α_2 , and β_2 are parameters to be determined.

Using equations (5) and (8), one obtains a set of six simultaneous nonlinear equations of degrees ranging from 2 to 12, which can be solved for the parameters of equation (8). These equations would be difficult to solve for the six unknowns. Fortunately, a simple approximate method for obtaining these parameters was found. As will be seen later, the errors resulting from the approximation must be insignificant.

An inspection of figures 1 and 2 with the basic shape of the gamma distribution in mind suggests that the contribution to $n(r)$ from $\Gamma(r, \alpha_1, \beta_1)$ comes from sizes less than about 1.5 μm radius and that the contribution from $\Gamma(r, \alpha_2, \beta_2)$ comes from radii greater than 1.5 μm . With this in mind, each drop-size distribution was separated into two distributions with the 1.5 μm radius as the separation point. (The 1.5 μm separation point may be an instrument artifact according to Pinnick and Auvermann.¹³) The first and second moments and the number concentrations of particles were computed independently for each portion. The computed number of particles provides values for N_1 and N_2 . The values of α 's and β 's are obtained from equations (6) and (7) in an iterative fashion. Since equation (7) will usually not provide an integer value for α , the value so obtained is rounded to the nearest positive integer. This value of α is then substituted into the first moment equation of (6) to solve for β .

Frequency distributions of α_1 and α_2 values are shown in table 2. The table shows that 6 and 3 are the most likely values for α_1 and α_2 , respectively. Consequently, these values were selected as fixed model

¹³R. G. Pinnick and H. J. Auvermann, 1979, "Response Characteristics of Knollenberg Light-Scattering Aerosol Counters," J Aerosol Sci, 10:55-74

TABLE 2. FREQUENCY OF OCCURRENCE OF VALUES α_1 AND α_2

	Value of α_1				
	4	5	6	7	8
22 Feb 78	1	65	98	0	0
4 Mar 78	10	42	40	7	11

	Value of α_2						
	0	1	2	3	4	5	6
22 Feb 78	8	49	12	62	24	2	5
4 Mar 78	1	1	11	22	18	14	9

parameters. The β_1 values were then recomputed by using $\alpha_1 = 6$ according to the first moment equation for all cases where the original values of α_1 differed from 6. A similar recalculation of some of the β_2 values was also required. Once these computations were completed, curve fitting techniques were used to obtain equations relating N_1 , N_2 , β_1 , and β_2 to visibility.

To simplify the data handling procedure and preclude bias towards the lower visibility data, the visibility range was segmented into logarithmically equally spaced intervals and mean values were computed for each interval. The results for N_1 , β_1 , and β_2 together with the corresponding equations obtained by the least squares curve fitting technique are presented in figures 5, 6, and 7. These results indicate that N_1 , β_1 , and β_2 can be related to visibility V through the following formulas:

$$N_1 = 446 V^{-0.106}, \quad (9)$$

$$\beta_1 = 0.09 - 0.2 \log V, \quad (10)$$

and

$$\beta_2 = 0.63 V^{-0.076}. \quad (11)$$

A preliminary equation for N_2 was obtained by the least squares procedure, and simulated drop-size distributions were computed for a range of visibilities. The N_2 values were then modified to "fine tune" the model until visibilities computed from the simulated distributions agreed with the input visibilities. Figure 8 shows the results of such "fine tuning," and the equations for N_2 are given below:

$$\begin{aligned} N_2 &= 36 V^{-1} && \text{for } V < 0.5 \text{ km} \\ &= 29.4 V^{-1.11} && \text{for } V = 0.5 \text{ km} \end{aligned} \quad (12)$$

Evaluation of Model Outputs

Equations (9) through (12) together with the values $\alpha_1 = 6$ and $\alpha_2 = 3$ provide the parameters to be used in equation (8) to simulate a dropsize distribution corresponding to a given or an observed visibility. With a distribution known, it is a simple matter to compute the resulting extinction or transmission of any desired wavelength. As discussed earlier, the model is not intended to reproduce all the details of the measurements; the goal was to simulate their principal characteristics and extinction properties. An example of the model's capability to satisfy the first objective is shown in figure 9. The comparison of the measurement with simulation can be considered excellent for radii

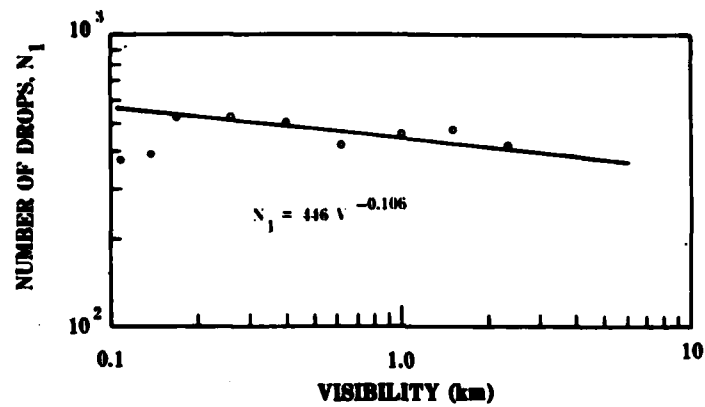


Figure 5. The number of drops in the first mode as a function of visibility in a least-squares fit.

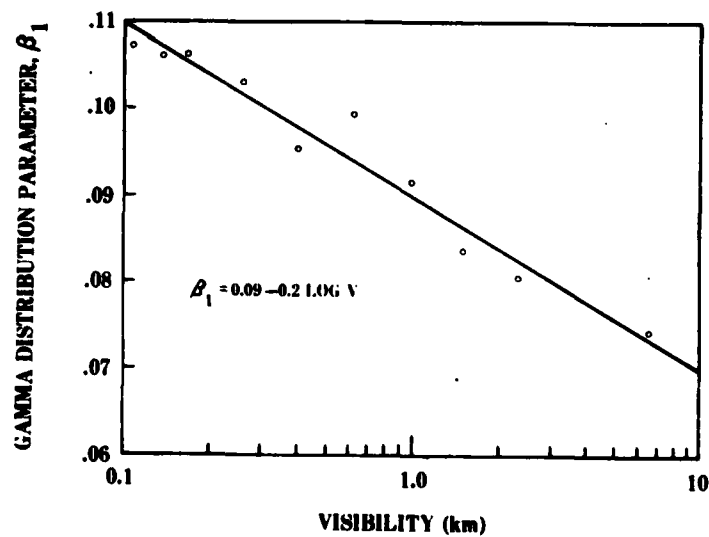


Figure 6. The gamma distribution parameter of the first mode as a function of visibility in a least-squares fit.

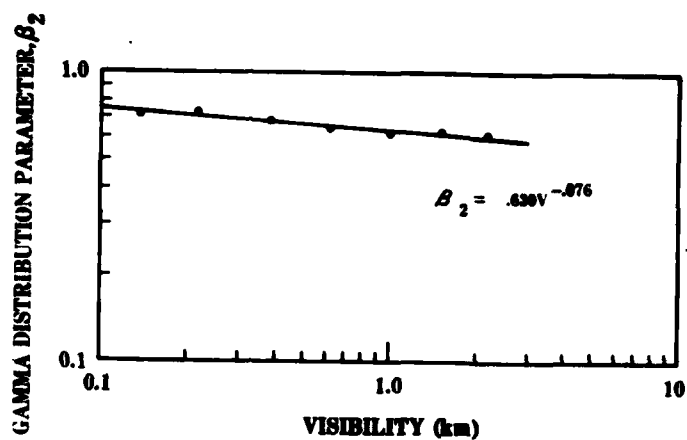


Figure 7. The gamma distribution parameter of the second mode as a function of visibility in a least-squares fit.

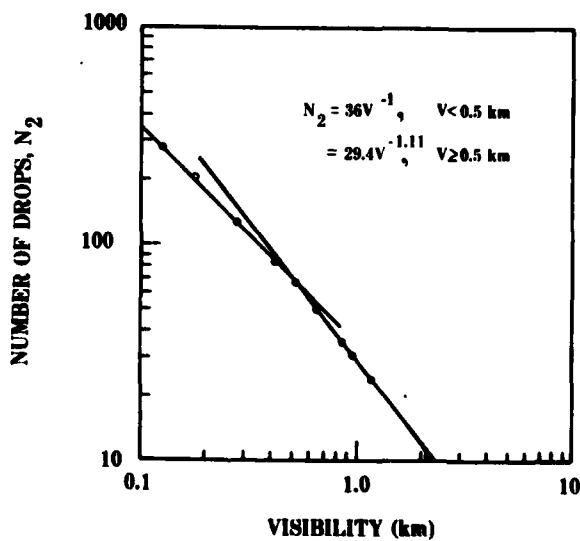


Figure 8. The number of drops in the second mode as a function of visibility in a fine-tuned least squares fit.

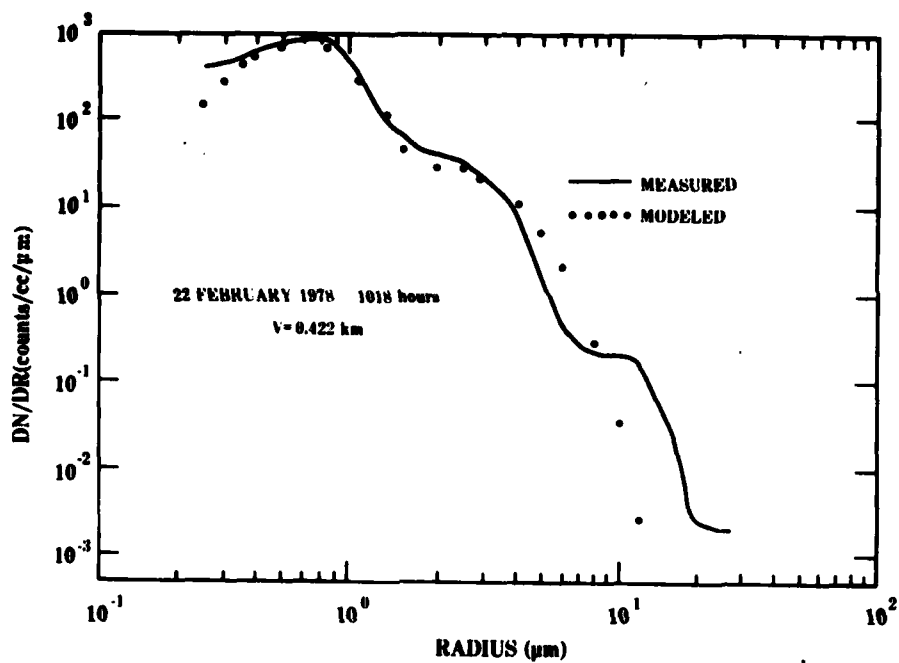


Figure 9. An example of how well the model distribution matches the observed distribution for visibility = 0.422 km.

smaller than about $10\mu\text{m}$. The model cannot reproduce the apparent third mode between $10\mu\text{m}$ and $15\mu\text{m}$ radii. This apparent third mode, which can also be seen in figure 1, appears in about one-half of the observations. This occurrence is not at all surprising, as may be deduced from a theoretical study by Neiburger and Chien.¹⁴ In this study, they succeeded in generating a bimodal drop-size distribution in the fog sector after some 50 minutes of droplet growth under the influence of droplet collision and coalescence.

Liquid water content and extinction coefficient for wavelengths of $3.8\mu\text{m}$ and $10\mu\text{m}$ computed from the model drop-size distributions were compared with those derived from corresponding measured ones of 22 February 1978 and 4 March 1978. As before, mean values for specific visibility intervals were also computed. These values are tabulated in table 3. A cursory comparison of the values of the corresponding parameters shows that deviations of the model values are on the average no greater than $\pm 15\%$ of those derived from observations--well within the measurement capability of the particle counter in current use.

Concluding Remarks and Some Observations

The methodology which has been developed and exploited in this report provides a capability to generate bimodal drop-size distributions consisting of both the haze and fog sectors commensurate with measurement data (at least in the case of the Meppen fogs) and possesses the additional capability to provide a distribution corresponding to a given or observed visibility. The model distribution so established may then be used to calculate extinction coefficients at other wavelengths.

Although the equations presented herein do not provide the parameters for depicting all types of haze/fog drop-size distributions, they are nevertheless quite adequate in representing most of the observations taken at Meppen, with the possible exception of those of 19 February 1978. It may thus be said that the approach used for modeling the Meppen fogs with a bimodal gamma distribution could be readily applied to other fog data. In concluding this report, we make a few observations about the difficulties encountered in haze/fog modeling as a result of the experiences gained in our thoroughgoing analysis of the Meppen fogs.

1. There are strong indications that, because of the continual presence of submicron-sized pollution particles which may be too tiny or may not be hygroscopic enough to grow into fog droplets, there will always be a haze regime in a fog, the magnitude of which depends upon

¹⁴M. Neiburger and C. W. Chien, 1960, "Computations of the Growth of Cloud Drops by Condensation Using an Electronic Digital Computer," Phys of Precipitation, Geophys. Monor. No. 5, Amer. Geophys. Union, Washington, DC, 191-210

TABLE 3. COMPARISON OF DERIVED QUANTITIES FROM
MEASURED AND MODELED SIZE DISTRIBUTIONS.
PRIMED QUANTITIES INDICATE MODELED VALUES.

Visibility	Lwc	Lwc'	K _{3.8}	K _{3.8} '	K ₁₀ '	K ₁₀ '
<u>4 March 1978</u>						
6.640	0.0004	0.0003	0.162	0.241	0.028	0.026
1.000	0.0046	0.0045	3.58	3.27	0.512	0.655
0.614	0.0087	0.0102	6.86	6.43	1.028	1.327
0.380	0.0158	0.0143	12.79	11.83	1.98	2.54
0.201	0.0410	0.0440	28.45	26.47	5.64	5.02
0.095	0.1110	0.0985	56.57	56.82	16.74	14.02
0.065	0.1750	0.1567	81.68	87.81	27.48	22.62

<u>22 February 1978</u>						
2.300	0.0016	0.0018	0.633	1.01	0.189	0.158
1.490	0.0033	0.0031	1.395	1.85	0.453	0.364
0.980	0.0065	0.0054	2.67	3.67	0.842	0.979
0.630	0.0131	0.0101	5.27	6.37	2.02	1.31
0.390	0.0287	0.0180	9.71	10.05	4.83	2.42
0.251	0.0469	0.0313	17.01	19.18	7.64	4.29
0.160	0.0691	0.0533	29.14	31.87	11.03	7.45
0.099	0.1047	0.0949	52.59	54.88	16.29	13.50
0.064	0.2335	0.1599	72.33	89.42	38.81	23.09

the state of pollution at a locality. Therefore, one would expect to find bimodal drop-size spectra in a fog observed with an optical particle counter capable of measuring submicron-sized particles. As the fog evolves and grows, a third mode generally appears under the influence of droplet collision and coalescence. Further evidence of this may be found in Jiusto.¹⁵ Since droplet collision, collection, and coalescence are stochastic in nature,¹⁶ fog drop-size spectra may well be multimodal as noted by Eldridge.¹⁷ Our present approach merely strikes for a compromise.

2. In the absence of condensation nuclei, there would be no haze or fog at the kind of saturation and supersaturation found in the atmosphere. An abundance of nuclei of substantial sizes would form fog in a rather slightly supersaturated or barely saturated atmosphere, but the nuclei are subject to gravitational settling as well as washout. Thus, as a fog persists under a given synoptic situation for 2 or more days, one would expect that its drop-size spectra would change from day to day for the above reasons. This tendency to change may explain why the spectra of 19 February 1978, as shown in figure 2, differed considerably from the others.

3. The above observations then lead to a third one. Regardless of whether meteorological factors will or will not enter into our modeling considerations, it is imperative to have some knowledge of the pollution state such as light, moderate, or heavy pollution as well as of the abundance of cloud/fog condensation nuclei at a locality. With this knowledge, it would then become possible to refine our model categories to be suitable for use in a realistic battlefield environment.

¹⁵J. E. Jiusto, 1979, Considerations in the Optical Characterization of the Atmosphere, ASL-CR-79-0100-3, US Army Atmospheric Sciences Laboratory, White Sands Missile Range, NM, 26 pages

¹⁶H. R. Pruppacher and J. D. Klett, 1978, Microphysics of Clouds and Precipitation, Reidel, Boston, MA, 714 pages

¹⁷R. G. Eldridge, 1966, "Haze and Fog Aerosol Distributions," J Atmos Sci, 23:605-613

REFERENCES

1. Mason, B. J., 1971, The Physics of Clouds, Oxford University Press.
2. Hindman, E. E., II, and O. E. R. Heimdahl, 1977, "Submicron Haze Droplets and their Influence on Visibility in Fog," preprint, 6th Conference Inadvertent and Planned Weather Modification, Am Meteorol Soc, Boston, MA, 10-13.
3. Fletcher, N. H., 1962, The Physics of Rainclouds, Cambridge University Press.
4. Low, R. D. H., L. D. Duncan, and Y. Y. R. Hsiao, 1979, Microphysical and Optical Properties of California Coastal Fogs at Fort Ord, ASL-TR-0034, US Army Atmospheric Sciences Laboratory, White Sands Missile Range, NM.
5. Khrgian, A. Kh., Ed., 1963, Cloud Physics, Israel Program for Scientific Translations, Jerusalem.
6. Levin, L. M., 1958, "Functions to Represent Drop-size Distributions in Clouds," Izv Geofiz Ser, 10:1211-1221 (English version).
7. Khrgian, A. Kh., and I. P. Mazin, 1952, "Distribution of Drops According to Size in Clouds," Trudy Tsen Aero Obs, 7:56-61 (English version).
8. Deirmendjian, D., 1964, "Scattering and Polarization Properties of Water Clouds and Hazes in the Visible and Infrared," Appl Opt, 3:187-196.
9. Tampieri, F., and C. Tomasi, 1976, "Size Distribution Models of Fog and Cloud Droplets in Terms of the Modified Gamma Function," Tellus, 28:333-347.
10. Twomey, S., 1977, Atmospheric Aerosols, Elsevier, NY.
11. Zuev, V. E., 1970, Atmospheric Transparency in the Visible and in the Infrared, Israel Program for Scientific Translations, Jerusalem.
12. Cross, T. S., and R. W. Fenn, Ed., 1978, OPAQUE Aerosol Counter Intercomparison, 25 April 1977--4 May 1977, AFGL-TR-78-0004, USAF Geophysics Laboratory, Hanscom AFB, MA.
13. Pinnick, R. G., and H. J. Auvermann, 1979, "Response Characteristics of Knollenberg Light-Scattering Aerosol Counters," J Aerosol Sci, 10:55-74.

14. Neiburger, M., and C. W. Chien, 1960, "Computations of the Growth of Cloud Drops by Condensation Using an Electronic Digital Computer," Phys of Precipitation, Geophys. Monor. No. 5, Amer. Geophys. Union, Washington, DC, 191-210.

15. Jiusto, J. E., 1979, Considerations in the Optical Characterization of the Atmosphere, ASL-CR-79-0100-3, US Army Atmospheric Sciences Laboratory, White Sands Missile Range, NM.

16. Pruppacher, H. R., and J. D. Klett, 1978, Microphysics of Clouds and Precipitation, Reidel, Boston, MA.

17. Eldridge, R. G., 1966, "Haze and Fog Aerosol Distributions," J Atmos Sci, 23:605-613.

ELECTRO-OPTICS DIVISION DISTRIBUTION LIST

Commander
US Army Aviation School
Fort Rucker, AL 36362

Commander
US Army Aviation Center
ATTN: ATZQ-D-MA (Mr. Oliver N. Heath)
Fort Rucker, AL 36362

Commander
US Army Aviation Center
ATTN: ATZQ-D-MS (Mr. Donald Wagner)
Fort Rucker, AL 36362

NASA/Marshall Space Flight Center
ATTN: ES-83 (Otha H. Vaughan, Jr.)
Huntsville, AL 35812

NASA/Marshall Space Flight Center
Atmospheric Sciences Division
ATTN: Code ES-81 (Dr. William W. Vaughan)
Huntsville, AL 35812

Nichols Research Corporation
ATTN: Dr. Lary W. Pinkley
4040 South Memorial Parkway
Huntsville, AL 35802

Commander
US Army Missile Command
ATTN: DRSMI-OG (Mr. Donald R. Peterson)
Redstone Arsenal, AL 35809

Commander
US Army Missile Command
ATTN: DRSMI-OGA (Dr. Bruce W. Fowler)
Redstone Arsenal, AL 35809

Commander
US Army Missile Command
ATTN: DRSMI-REL (Dr. George Emmons)
Redstone Arsenal, AL 35809

Commander
US Army Missile Command
ATTN: DRSMI-REO (Huey F. Anderson)
Redstone Arsenal, AL 35809

Commander
US Army Missile Command
ATTN: DRSMI-REO (Mr. Maxwell W. Harper)
Redstone Arsenal, AL 35809

Commander
US Army Missile Command
ATTN: DRSMI-REO (Mr. Gene Widenhofer)
Redstone Arsenal, AL 35809

Commander
US Army Missile Command
ATTN: DRSMI-RHC (Dr. Julius Q. Lilly)
Redstone Arsenal, AL 35809

Commander
US Army Missile Command
Redstone Scientific Information Center
ATTN: DRSMI-RPRD (Documents Section)
Redstone Arsenal, AL 35809

Commander
US Army Missile Command
ATTN: DRSMI-RRA (Dr. Oskar Essenwanger)
Redstone Arsenal, AL 35809

Commander
US Army Missile Command
ATTN: DRSMI-RRO (Mr. Charles Christensen)
Redstone Arsenal, AL 35809

Commander
US Army Missile Command
ATTN: DRSMI-RRO (Dr. George A. Tanton)
Redstone Arsenal, AL 35809

Commander
US Army Communications Command
ATTN: CC-OPS-PP
Fort Huachuca, AZ 85613

Commander
US Army Intelligence Center & School
ATTN: ATSI-CD-CS (Mr. Richard G. Cundy)
Fort Huachuca, AZ 85613

Commander
US Army Intelligence Center & School
ATTN: ATSI-CD-MD (Mr. Harry Wilder)
Fort Huachuca, AZ 85613

Commander
US Army Intelligence Center & School
ATTN: ATSI-CS-C (2LT Coffman)
Fort Huachuca, AZ 85613

Commander
US Army Yuma Proving Ground
ATTN: STEYP-MSA-TL
Bldg 2105
Yuma, AZ 85364

Northrop Corporation
Electro-Mechanical Division
ATTN: Dr. Richard D. Tooley
500 East Orangethorpe Avenue
Anaheim, CA 92801

Commander
Naval Weapons Center
ATTN: Code 3918 (Dr. Alexis Shlanta)
China Lake, CA 93555

Hughes Helicopters
Army Advanced Attack Helicopter Weapons
ATTN: Mr. Charles R. Hill
Centinela and Teale Streets
Bldg 305, MS T-73A
Culter City, CA 90230

Commander
US Army Combat Developments
Experimentation Command
ATTN: ATEC-PL-M (Mr. Gary G. Love)
Fort Ord, CA 93941

SRI International
ATTN: K2060/Dr. Edward E. Uthe
333 Ravenswood Avenue
Menlo Park, CA 94025

SRI International
ATTN: Mr. J. E. Van der Laan
333 Ravenswood Avenue
Menlo Park, CA 94025

Joane May
Naval Environmental Prediction
Research Facility (NEPRF)
ATTN: Library
Monterey, CA 93940

Sylvania Systems Group,
Western Division
GTE Products Corporation
ATTN: Technical Reports Library
P.O. Box 205
Mountain View, CA 94042

Sylvania Systems Group
Western Division
GTE Products Corporation
ATTN: Mr. Lee W. Carrier
P.O. Box 188
Mountain View, CA 94042

Pacific Missile Test Center
Geophysics Division
ATTN: Code 3253
Point Mugu, CA 93042

Pacific Missile Test Center
Geophysics Division
ATTN: Code 3253 (Terry E. Battalino)
Point Mugu, CA 93042

Effects Technology Inc.
ATTN: Mr. John D. Carlyle
5383 Hollister Avenue
Santa Barbara, CA 93111

Commander
Naval Ocean Systems Center
ATTN: Code 532 (Dr. Juergen Richter)
San Diego, CA 92152

Commander
Naval Ocean Systems Center
ATTN: Code 5322 (Mr. Herbert G. Hughes)
San Diego, CA 92152

Commander
Naval Ocean Systems Center
ATTN: Code 4473 (Tech Library)
San Diego, CA 92152

The RAND Corporation
ATTN: Ralph Huschke
1700 Main Street
Santa Monica, CA 90406

Particle Measuring Systems, Inc.
ATTN: Dr. Robert G. Knollenberg
1855 South 57th Court
Boulder, CO 80301

US Department of Commerce
National Oceanic and Atmospheric Admin
Environmental Research Laboratories
ATTN: Library, R-51, Technical Reports
325 Broadway
Boulder, CO 80303

US Department of Commerce
National Oceanic and Atmospheric Admin
Environmental Research Laboratories
ATTN: R45X3 (Dr. Vernon E. Derr)
Boulder, CO 80303

US Department of Commerce
National Telecommunications and
Information Administration
Institute for Telecommunication Sciences
ATTN: Code 1-3426 (Dr. Hans J. Liebe)
Boulder, CO 80303

AFATL/DLODL
Technical Library
Eglin AFB, FL 32542

Commanding Officer
Naval Training Equipment Center
ATTN: Technical Information Center
Orlando, FL 32813

Georgia Institute of Technology
Engineering Experiment Station
ATTN: Dr. Robert W. McMillan
Atlanta, GA 30332

Georgia Institute of Technology
Engineering Experiment Station
ATTN: Dr. James C. Wiltse
Atlanta, GA 30332

Commandant
US Army Infantry Center
ATTN: ATSH-CD-MS-E (Mr. Robert McKenna)
Fort Benning, GA 31805

Commander
US Army Signal Center & Fort Gordon
ATTN: ATZHCD-CS
Fort Gordon, GA 30905

Commander
US Army Signal Center & Fort Gordon
ATTN: ATZHCD-O
Fort Gordon, GA 30905

USAFETAC/DNE
ATTN: Mr. Charles Glauber
Scott AFB, IL 62225

Commander
Air Weather Service
ATTN: AWS/DNDP (LTC Kit G. Cottrell)
Scott AFB, IL 62225

Commander
Air Weather Service
ATTN: AWS/DOOF (MAJ Robert Wright)
Scott AFB, IL 62225

Commander
US Army Combined Arms Center
& Ft. Leavenworth
ATTN: ATZLCA-CAA-Q (Mr. H. Kent Pickett)
Fort Leavenworth, KS 66027

Commander
US Army Combined Arms Center
& Ft. Leavenworth
ATTN: ATZLCA-SAN (Robert DeKinder, Jr.)
Fort Leavenworth, KS 66027

Commander
US Army Combined Arms Center
& Ft. Leavenworth
ATTN: ATZLCA-SAN (Mr. Kent I. Johnson)
Fort Leavenworth, KS 66027

Commander
US Army Combined Arms Center
& Ft. Leavenworth
ATTN: ATZLCA-WE (LTC Darrell Holland)
Fort Leavenworth, KS 66027

President
USAARENBD
ATTN: ATZK-AE-TA (Dr. Charles R. Leake)
Fort Knox, KY 40121

Commander
US Army Armor Center and Fort Knox
ATTN: ATZK-CD-MS
Fort Knox, KY 40121

Commander
US Army Armor Center and Fort Knox
ATTN: ATZK-CD-SD
Fort Knox, KY 40121

Aerodyne Research Inc.
ATTN: Dr. John F. Ebersole
Crosby Drive
Bedford, MA 01730

Commander
Air Force Geophysics Laboratory
ATTN: OPA (Dr. Robert W. Fenn)
Hanscom AFB, MA 01731

Commander
Air Force Geophysics Laboratory
ATTN: OPI (Dr. Robert A. McClatchey)
Hanscom AFB, MA 01731

Massachusetts Institute of Technology
Lincoln Laboratory
ATTN: Dr. T. J. Gobllick, B-370
P.O. Box 73
Lexington, MA 02173

Massachusetts Institute of Technology
Lincoln Laboratory
ATTN: Dr. Michael Gruber
P.O. Box 73
Lexington, MA 02173

Raytheon Company
Equipment Division
ATTN: Dr. Charles M. Sonnenschein
430 Boston Post Road
Wayland, MA 01778

Commander
US Army Ballistic Research Laboratory/
ARRADCOM
ATTN: DRDAR-BLB (Mr. Richard McGee)
Aberdeen Proving Ground, MD 21005

Commander/Director
Chemical Systems Laboratory
US Army Armament Research
& Development Command
ATTN: DRDAR-CLB-PS (Dr. Edward Stuebing)
Aberdeen Proving Ground, MD 21010

Commander/Director
Chemical Systems Laboratory
US Army Armament Research
& Development Command
ATTN: DRDAR-CLB-PS (Mr. Joseph Vervier)
Aberdeen Proving Ground, MD 21010

Commander/Director
Chemical Systems Laboratory
US Army Armament Research
& Development Command
ATTN: DRDAR-CLY-A (Mr. Ronald Pennsyle)
Aberdeen Proving Ground, MD 21010

Commander
US Army Ballistic Research Laboratory/
ARRADCOM
ATTN: DRDAR-TSB-S (STINFO)
Aberdeen Proving Ground, MD 21005

Commander
US Army Electronics Research
& Development Command
ATTN: DRDEL-CCM (W. H. Pepper)
Adelphi, MD 20783

Commander
US Army Electronics Research
& Development Command
ATTN: DRDEL-CG/DRDEL-DC/DRDEL-CS
2800 Powder Mill Road
Adelphi, MD 20783

Commander
US Army Electronics Research
& Development Command
ATTN: DRDEL-CT
2800 Powder Mill Road
Adelphi, MD 20783

Commander
US Army Electronics Research
& Development Command
ATTN: DRDEL-PAO (Mr. Steven Kimmel)
2800 Powder Mill Road
Adelphi, MD 20783

Project Manager
Smoke/Obscurants
ATTN: DRDPM-SMK
(Dr. Anthony Van de Wal, Jr.)
Aberdeen Proving Ground, MD 21005

Project Manager
Smoke/Obscurants
ATTN: DRDPM-SMK-T (Mr. Sidney Gerard)
Aberdeen Proving Ground, MD 21005

Commander
US Army Test & Evaluation Command
ATTN: DRSTE-AD-M (Mr. Warren M. Baity)
Aberdeen Proving Ground, MD 21005

Commander
US Army Test & Evaluation Command
ATTN: DRSTE-AD-M (Dr. Norman E. Pentz)
Aberdeen Proving Ground, MD 21005

Director
US Army Materiel Systems Analysis Activity
ATTN: DRXSY-AAM (Mr. William Smith)
Aberdeen Proving Ground, MD 21005

Director
US Army Materiel Systems Analysis Activity
ATTN: DRXSY-CS (Mr. Philip H. Beavers)
Aberdeen Proving Ground, MD 21005

Director
US Army Materiel Systems Analysis Activity
ATTN: DRXSY-GB (Wilbur L. Warfield)
Aberdeen Proving Ground, MD 21005

Director
US Army Materiel Systems Analysis Activity
ATTN: DRXSY-GP (Mr. Fred Campbell)
Aberdeen Proving Ground, MD 21005

Director
US Army Materiel Systems Analysis Activity
ATTN: DRXSY-GS
(Mr. Michael Starks/Mr. Julian Chernick)
Aberdeen Proving Ground, MD 21005

Director
US Army Materiel Systems Analysis Activity
ATTN: DRXSY-J (Mr James F. O'Bryon)
Aberdeen Proving Ground, MD 21005

Director
US Army Materiel Systems Analysis Activity
ATTN: DRXSY-LM (Mr. Robert M. Marchetti)
Aberdeen Proving Ground, MD 21005

Commander
Harry Diamond Laboratories
ATTN: Dr. William W. Carter
2800 Powder Mill Road
Adelphi, MD 20783

Commander
Harry Diamond Laboratories
ATTN: DELHD-R-CM (Mr. Robert McCoskey)
2800 Powder Mill Road
Adelphi, MD 20783

Commander
Harry Diamond Laboratories
ATTN: DELHD-R-CM-NM (Dr. Robert Humphrey)
2800 Powder Mill Road
Adelphi, MD 20783

Commander
Harry Diamond Laboratories
ATTN: DELHD-R-CM-NM (Dr. Z. G. Sztankay)
2800 Powder Mill Road
Adelphi, MD 20783

Commander
Harry Diamond Laboratories
ATTN: DELHD-R-CM-NM (Dr. Joseph Nemarich)
2800 Powder Mill Road
Adelphi, MD 20783

Commander
Air Force Systems Command
ATTN: WER (Mr. Richard F. Picanso)
Andrews AFB, MD 20334

Martin Marietta Laboratories
ATTN: Jar Mo Chen
1450 South Rolling Road
Baltimore, MD 21227

Commander
US Army Concepts Analysis Agency
ATTN: CSCA-SMC (Mr. Hal E. Hock)
8120 Woodmont Avenue
Bethesda, MD 20014

Director
National Security Agency
ATTN: R52/Dr. Douglas Woods
Fort George G. Meade, MD 20755

Chief
Intelligence Materiel Development
& Support Office
US Army Electronic Warfare Laboratory
ATTN: DELEW-I (LTC Kenneth E. Thomas)
Fort George G. Meade, MD 20755

The John Hopkins University
Applied Physics Laboratory
ATTN: Dr. Michael J. Lun
John Hopkins Road
Laurell, MD 20810

Dr. Stephen T. Hanley
1720 Rhodesia Avenue
Oxon Hill, MD 20022

Science Applications Inc.
ATTN: Mr. G. D. Currie
15 Research Drive
Ann Arbor, MI 48103

Science Applications Inc.
ATTN: Dr. Robert E. Turner
15 Research Drive
Ann Arbor, MI 48103

Commander
US Army Tank-Automotive Research
& Development Command
ATTN: DRDTA-ZSC (Mr. Harry Young)
Warren, MI 48090

Commander
US Army Tank Automotive Research
& Development Command
ATTN: DRDTA-ZSC (Mr. Wallace Mick, Jr.)
Warren, MI 48090

Dr. A. D. Belmont
Research Division
Control Data Corporation
P.O. Box 1249
Minneapolis, MN 55440

Director
US Army Engr Waterways Experiment Station
ATTN: WESEN (Mr. James Mason)
P.O. Box 631
Vicksburg, MS 39180

Commander
US Army Research Office
ATTN: DRXRO-GS (Dr. Leo Alpert)
P.O. Box 12211
Research Triangle Park, NC 27709

Commander
US Army Research Office
ATTN: DRXRO-PP (Brenda Mann)
P.O. Box 12211
Research Triangle Park, NC 27709

Commander
US Army Cold Regions Research
& Engineering Laboratory
ATTN: CRREL-RD (Dr. K. F. Sterrett)
Hanover, NH 03755

Commander/Director
US Army Cold Regions Research
& Engineering Laboratory
ATTN: CRREL-RG (Mr. George Aitken)
Hanover, NH 03755

Commander
US Army Cold Regions Research
& Engineering Laboratory
ATTN: CRREL-RG (Mr. Roger H. Berger)
Hanover, NH 03755

Commander
US Army Armament Research
& Development Command
ATTN: DRDAR-AC (Mr. James Greenfield)
Dover, NJ 07801

Commander
US Army Armament Research
& Development Command
ATTN: DRDAR-TSS (Bldg #59)
Dover, NJ 07801

Commander
US Army Armament Research
& Development Command
ATTN: DRCPM-CAWS-EI (Mr. Peteris Jansons)
Dover, NJ 07801

Commander
US Army Armament Research
& Development Command
ATTN: DRCPM-CAWS-EI (Mr. G. H. Waldron)
Dover, NJ 07801

Deputy Joint Project Manager
for Navy/USMC SAL GP
ATTN: DRCPM-CAWS-NV (CPT Joseph Miceli)
Dover, NJ 07801

Commander/Director
US Army Combat Surveillance & Target
Acquisition Laboratory
ATTN: DELCS-I (Mr. David Longinotti)
Fort Monmouth, NJ 07703

Commander/Director
US Army Combat Surveillance & Target
Acquisition Laboratory
ATTN: DELCS-PE (Mr. Ben A. Di Campli)
Fort Monmouth, NJ 07703

Commander/Director
US Army Combat Surveillance & Target
Acquisition Laboratory
ATTN: DELCS-R-S (Mr. Donald L. Foiani)
Fort Monmouth, NJ 07703

Director
US Army Electronics Technology &
Devices Laboratory
ATTN: DELET-DD (S. Danko)
Fort Monmouth, NJ 07703

Project Manager
FIREFINDER/REMBASS
ATTN: DRCPM-FFR-TM (Mr. John M. Bialo)
Fort Monmouth, NJ 07703

Commander
US Army Electronics Research
& Development Command
ATTN: DRDEL-SA (Dr. Walter S. McAfee)
Fort Monmouth, NJ 07703

OLA, 2WS (MAC)
Holloman AFB, NM 88330

Commander
Air Force Weapons Laboratory
ATTN: AFWL/WE (MAJ John R. Elrick)
Kirtland, AFB, NM 87117

Director
USA TRADOC Systems Analysis Activity
ATTN: ATAA-SL
White Sands Missile Range, NM 88002

Director
USA TRADOC Systems Analysis Activity
ATTN: ATAA-SL (Dolores Anguiano)
White Sands Missile Range, NM 88002

Director
USA TRADOC Systems Analysis Activity
ATTN: ATAA-TDB (Mr. Louie Dominguez)
White Sands Missile Range, NM 88002

Director
USA TRADOC Systems Analysis Activity
ATTN: ATAA-TDB (Mr. William J. Leach)
White Sands Missile Range, NM 88002

Director
USA TRADOC Systems Analysis Activity
ATTN: ATAA-TGP (Mr. Roger F. Willis)
White Sands Missile Range, NM 88002

Director
Office of Missile Electronic Warfare
ATTN: DELEW-M-STO (Dr. Steven Kovel)
White Sands Missile Range, NM 88002

Office of the Test Director
Joint Services EO GW CM Test Program
ATTN: DRXDE-TD (Mr. Weldon Findley)
White Sands Missile Range, NM 88002

Commander
US Army White Sands Missile Range
ATTN: STEWS-PT-AL (Laurel B. Saunders)
White Sands Missile Range, NM 88002

Commander
US Army R&D Coordinator
US Embassy - Bonn
Box 165
APO New York 09080

Grumman Aerospace Corporation
Research Department - MS A08-35
ATTN: John E. A. Selby
Bethpage, NY 11714

Rome Air Development Center
ATTN: Documents Library
TSLD (Bette Smith)
Griffiss AFB, NY 13441

Dr. Roberto Vaglio-Laurin
Faculty of Arts and Science
Dept. of Applied Science
26-36 Stuyvesant Street
New York, NY 10003

Air Force Wright Aeronautical Laboratories/
Avionics Laboratory
ATTN: AFWAL/AARI-3 (Mr. Harold Geltmacher)
Wright-Patterson AFB, OH 45433

Air Force Wright Aeronautical Laboratories/
Avionics Laboratory
ATTN: AFWAL/AARI-3 (CPT William C. Smith)
Wright-Patterson AFB, OH 45433

Commandant
US Army Field Artillery School
ATTN: ATSF-CF-R (CPT James M. Watson)
Fort Sill, OK 73503

Commandant
US Army Field Artillery School
ATTN: ATSF-CD-MS
Fort Sill, OK 73503

Commandant
US Army Field Artillery School
ATTN: ATSF-CF-R
Fort Sill, OK 73503

Commandant
US Army Field Artillery School
ATTN: NOAA Liaison Officer
(CDR Jeffrey G. Carlen)
Fort Sill, OK 73503

Commandant
US Army Field Artillery School
Morris Swett Library
ATTN: Reference Librarian
Fort Sill, OK 73503

Commander
Naval Air Development Center
ATTN: Code 301 (Mr. George F. Eck)
Warminster, PA 18974

The University of Texas at El Paso
Electrical Engineering Department
ATTN: Dr. Joseph H. Pierluissi
El Paso, TX 79968

Commandant
US Army Air Defense School
ATTN: ATSA-CD-SC-A (CPT Charles T. Thorn)
Fort Bliss, TX 79916

Commander
HQ, TRADOC Combined Arms Test Activity
ATTN: ATCAT-OP-Q (CPT Henry C. Cobb, Jr.)
Fort Hood, TX 76544

Commander
HQ, TRADOC Combined Arms Test Activity
ATTN: ATCAT-SCI (Dr. Darrell W. Collier)
Fort Hood, TX 76544

Commander
US Army Dugway Proving Ground
ATTN: STEDP-MT-DA-L
Dugway, UT 84022

Commander
US Army Dugway Proving Ground
ATTN: STEDP-MT-DA-M (Mr. Paul E. Carlson)
Dugway, UT 84022

Commander
US Army Dugway Proving Ground
ATTN: STEDP-MT-DA-T (Mr. John Trethewey)
Dugway, UT 84022

Commander
US Army Dugway Proving Ground
ATTN: STEDP-MT-DA-T (Mr. William Peterson)
Dugway, UT 84022

Defense Documentation Center
ATTN: DDC-TCA
Cameron Station Bldg 5
Alexandria, VA 22314
12

Ballistic Missile Defense Program Office
ATTN: DACS-BMT (Colonel Harry F. Ennis)
5001 Eisenhower Avenue
Alexandria, VA 22333

Defense Technical Information Center
ATTN: DDA-2 (Mr. James E. Shafer)
Cameron Station, Bldg 5
Alexandria, VA 22314

Commander
US Army Materiel Development
& Readiness Command
ATTN: DRCBSI-EE (Mr. Albert Giambalvo)
5001 Eisenhower Avenue
Alexandria, VA 22333

Commander
US Army Materiel Development
& Readiness Command
ATTN: DRCLDC (Mr. James Bender)
5001 Eisenhower Avenue
Alexandria, VA 22333

Defense Advanced Rsch Projects Agency
ATTN: Steve Zakanyez
1400 Wilson Blvd
Arlington, VA 22209

Defense Advanced Rsch Projects Agency
ATTN: Dr. James Tegnella
1400 Wilson Blvd
Arlington, VA 22209

Institute for Defense Analyses
ATTN: Mr. Lucien M. Biberman
400 Army-Navy Drive
Arlington, VA 22202

Institute for Defense Analyses
ATTN: Dr. Ernest Bauer
400 Army-Navy Drive
Arlington, VA 22202

Institute of Defense Analyses
ATTN: Dr. Hans G. Wolfhard
400 Army-Navy Drive
Arlington, VA 22202

System Planning Corporation
ATTN: Mr. Daniel Friedman
1500 Wilson Boulevard
Arlington, VA 22209

System Planning Corporation
ATTN: COL Hank Shelton
1500 Wilson Boulevard
Arlington, VA 22209

US Army Intelligence & Security Command
ATTN: Edwin Speakman, Scientific Advisor
Arlington Hall Station
Arlington, VA 22212

Commander
US Army Operational Test
& Evaluation Agency
ATTN: CSTE-ED (Mr. Floyd I. Hill)
5600 Columbia Pike
Falls Church, VA 22041

Commander and Director
US Army Engineer Topographic Laboratories
ATTN: ETL-GS-A (Mr. Thomas Neidringhaus)
Fort Belvoir, VA 22060

Director
US Army Night Vision &
Electro-Optics Laboratory
ATTN: DELNV-L (Dr. Rudolf G. Buser)
Fort Belvoir, VA 22060

Director
US Army Night Vision &
Electro-Optics Laboratory
ATTN: DELNV-L (Dr. Robert S. Rodhe)
Fort Belvoir, VA 22060

Director
US Army Night Vision &
Electro-Optics Laboratory
ATTN: DELNV-VI (Mr. Joseph R. Moulton)
Fort Belvoir, VA 22060

Director
US Army Night Vision &
Electro-Optics Laboratory
ATTN: DELNV-VI (Luanne P. Obert)
Fort Belvoir, VA 22060

Director
US Army Night Vision
& Electro-Optics Laboratory
ATTN: DELNV-VI (Mr. Thomas W. Cassidy)
Fort Belvoir, VA 22060

Director
US Army Night Vision &
Electro-Optics Laboratory
ATTN: DELNV-VI (Mr. Richard J. Bergemann)
Fort Belvoir, VA 22060

Director
US Army Night Vision &
Electro-Optics Laboratory
ATTN: DELNV-VI (Dr. James A. Ratches)
Fort Belvoir, VA 22060

Commander
US Army Training & Doctrine Command
ATTN: ATCD-AN
Fort Monroe, VA 23651

Commander
US Army Training & Doctrine Command
ATTN: ATCD-AN-M
Fort Monroe, VA 23651

Commander
US Army Training & Doctrine Command
ATTN: ATCD-F-A (Mr. Chris O'Connor, Jr.)
Fort Monroe, VA 23651

Commander
US Army Training & Doctrine Command
ATTN: ATCD-IE-R (Mr. David M. Ingram)
Fort Monroe, VA 23651

Commander
US Army Training & Doctrine Command
ATTN: ATCD-M-I/ATCD-M-A
Fort Monroe, VA 23651

Commander
US Army Training & Doctrine Command
ATTN: ATDOC-TA (Dr. Marvin P. Pastel)
Fort Monroe, VA 23651

Department of the Air Force
OL-I, AWS
Fort Monroe, VA 23651

Department of the Air Force
HQS 5 Weather Wing (MAC)
ATTN: 5 WW/DN
Langley Air Force Base, VA 23655

Commander
US Army INSCOM/Quest Research Corporation
ATTN: Mr. Donald Wilmot
6845 Elm Street, Suite 407
McLean, VA 22101

General Research Corporation
ATTN: Dr. Ralph Zirkind
7655 Old Springhouse Road
McLean, VA 22102

Science Applications, Inc.
8400 Westpark Drive
ATTN: Dr. John E. Cockayne
McLean, VA 22102

US Army Nuclear & Chemical Agency
ATTN: MONA-WE (Dr. John A. Berberet)
7500 Backlick Road, Bldg 2073
Springfield, VA 22150

Director
US Army Signals Warfare Laboratory
ATTN: DELSW-EA (Mr. Douglas Harkleroad)
Vint Hill Farms Station
Warrenton, VA 22186

Director
US Army Signals Warfare Laboratory
ATTN: DELSW-OS (Dr. Royal H. Burkhardt)
Vint Hill Farms Station
Warrenton, VA 22186

Commander
US Army Cold Regions Test Center
ATTN: STECR-TD (Mr. Jerold Barger)
APO Seattle, WA 98733

HQDA (SAUS-OR/Hunter M. Woodall, Jr./
Dr. Herbert K. Fallin)
Rm 2E 614, Pentagon
Washington, DC 20301

COL Elbert W. Friday, Jr.
OUSORE
Rm 3D 129, Pentagon
Washington, DC 20301

Defense Communications Agency
Technical Library Center
Code 222
Washington, DC 20305

Director
Defense Nuclear Agency
ATTN: Technical Library (Mrs. Betty Fox)
Washington, DC 20305

Director
Defense Nuclear Agency
ATTN: RAAE (Dr. Carl Fitz)
Washington, DC 20305

Director
Defense Nuclear Agency
ATTN: SPAS (Mr. Donald J. Kohler)
Washington, DC 20305

Defense Intelligence Agency
ATTN: DT/AC (LTC Robert Poplawski)
Washington, DC 20301

HQDA (DAMA-ARZ-D/Dr. Verderame)
Washington, DC 20310

HQDA (DAMI-ISP/Mr. Beck)
Washington, DC 20310

Department of the Army
Deputy Chief of Staff for
Operations and Plans
ATTN: DAMO-RQ
Washington, DC 20310

Department of the Army
Director of Telecommunications and
Command and Control
ATTN: DAMO-TCZ
Washington, DC 20310

Department of the Army
Assistant Chief of Staff for Intelligence
ATTN: DAMI-TS
Washington, DC 20310

HQDA (DAEN-RDM/Dr. de Percin)
Casimir Pulaski Building
20 Massachusetts Avenue
Room 6203
Washington, DC 20314

National Science Foundation
Division of Atmospheric Sciences
ATTN: Dr. Eugene W. Bierly
1800 G. Street, N.W.
Washington, DC 20550

Director
Naval Research Laboratory
ATTN: Code 4320 (Dr. Lothar H. Ruhnke)
Washington, DC 20375

Commanding Officer
Naval Research Laboratory
ATTN: Code 6009 (Dr. John MacCallum, Jr.)
Washington, DC 20375

Commanding Officer
Naval Research Laboratory
ATTN: Code 6530 (Mr. Raymond A. Patten)
Washington, DC 20375

Commanding Officer
Naval Research Laboratory
ATTN: Code 6533 (Dr. James A. Dowling)
Washington, DC 20375

ATMOSPHERIC SCIENCES RESEARCH PAPERS

1. Lindberg, J.D., "An Improvement to a Method for Measuring the Absorption Coefficient of Atmospheric Dust and other Strongly Absorbing Powders," ECOM-5565, July 1975.
2. Avara, Elton, P., "Mesoscale Wind Shears Derived from Thermal Winds," ECOM-5566, July 1975.
3. Gomez, Richard B., and Joseph H. Pierluissi, "Incomplete Gamma Function Approximation for King's Strong-Line Transmittance Model," ECOM-5567, July 1975.
4. Blanco, A.J., and B.F. Engebos, "Ballistic Wind Weighting Functions for Tank Projectiles," ECOM-5568, August 1975.
5. Taylor, Fredrick J., Jack Smith, and Thomas H. Pries, "Crosswind Measurements through Pattern Recognition Techniques," ECOM-5569, July 1975.
6. Walters, D.L., "Crosswind Weighting Functions for Direct-Fire Projectiles," ECOM-5570, August 1975.
7. Duncan, Louis D., "An Improved Algorithm for the Iterated Minimal Information Solution for Remote Sounding of Temperature," ECOM-5571, August 1975.
8. Robbiani, Raymond L., "Tactical Field Demonstration of Mobile Weather Radar Set AN/TPS-41 at Fort Rucker, Alabama," ECOM-5572, August 1975.
9. Miers, B., G. Blackman, D. Langer, and N. Lorimier, "Analysis of SMS/GOES Film Data," ECOM-5573, September 1975.
10. Manquero, Carlos, Louis Duncan, and Rufus Bruce, "An Indication from Satellite Measurements of Atmospheric CO₂ Variability," ECOM-5574, September 1975.
11. Petracca, Carmine, and James D. Lindberg, "Installation and Operation of an Atmospheric Particulate Collector," ECOM-5575, September 1975.
12. Avara, Elton P., and George Alexander, "Empirical Investigation of Three Iterative Methods for Inverting the Radiative Transfer Equation," ECOM-5576, October 1975.
13. Alexander, George D., "A Digital Data Acquisition Interface for the SMS Direct Readout Ground Station — Concept and Preliminary Design," ECOM-5577, October 1975.
14. Cantor, Israel, "Enhancement of Point Source Thermal Radiation Under Clouds in a Nonattenuating Medium," ECOM-5578, October 1975.
15. Norton, Colburn, and Glenn Hoidale, "The Diurnal Variation of Mixing Height by Month over White Sands Missile Range, N.M.," ECOM-5579, November 1975.
16. Avara, Elton P., "On the Spectrum Analysis of Binary Data," ECOM-5580, November 1975.
17. Taylor, Fredrick J., Thomas H. Pries, and Chao-Huan Huang, "Optimal Wind Velocity Estimation," ECOM-5581, December 1975.
18. Avara, Elton P., "Some Effects of Autocorrelated and Cross-Correlated Noise on the Analysis of Variance," ECOM-5582, December 1975.
19. Gillespie, Patti S., R.L. Armstrong, and Kenneth O. White, "The Spectral Characteristics and Atmospheric CO₂ Absorption of the Ho⁺ YLF Laser at 2.05 μ m," ECOM-5583, December 1975.
20. Novlan, David J. "An Empirical Method of Forecasting Thunderstorms for the White Sands Missile Range," ECOM-5584, February 1976.
21. Avara, Elton P., "Randomization Effects in Hypothesis Testing with Autocorrelated Noise," ECOM-5585, February 1976.
22. Watkins, Wendell R., "Improvements in Long Path Absorption Cell Measurement," ECOM-5586, March 1976.
23. Thomas, Joe, George D. Alexander, and Marvin Dubbin, "SATTEL — An Army Dedicated Meteorological Telemetry System," ECOM-5587, March 1976.
24. Kennedy, Bruce W., and Delbert Bynum, "Army User Test Program for the RDT&E-XM-75 Meteorological Rocket," ECOM-5588, April 1976.

25. Barnett, Kenneth M., "A Description of the Artillery Meteorological Comparisons at White Sands Missile Range, October 1974 - December 1974 ('PASS' - Prototype Artillery [Meteorological] Subsystem)," ECOM-5589, April 1976.
26. Miller, Walter B., "Preliminary Analysis of Fall-of-Shot From Project 'PASS'," ECOM-5590, April 1976.
27. Avara, Elton P., "Error Analysis of Minimum Information and Smith's Direct Methods for Inverting the Radiative Transfer Equation," ECOM-5591, April 1976.
28. Yee, Young P., James D. Horn, and George Alexander, "Synoptic Thermal Wind Calculations from Radiosonde Observations Over the Southwestern United States," ECOM-5592, May 1976.
29. Duncan, Louis D., and Mary Ann Seagraves, "Applications of Empirical Corrections to NOAA-4 VTPR Observations," ECOM-5593, May 1976.
30. Miers, Bruce T., and Steve Weaver, "Applications of Meteorological Satellite Data to Weather Sensitive Army Operations," ECOM-5594, May 1976.
31. Sharenow, Moses, "Redesign and Improvement of Balloon ML-566," ECOM-5595, June, 1976.
32. Hansen, Frank V., "The Depth of the Surface Boundary Layer," ECOM-5596, June 1976.
33. Pinnick, R.G., and E.B. Stenmark, "Response Calculations for a Commercial Light-Scattering Aerosol Counter," ECOM-5597, July 1976.
34. Mason, J., and G.B. Hoidale, "Visibility as an Estimator of Infrared Transmittance," ECOM-5598, July 1976.
35. Bruce, Rufus E., Louis D. Duncan, and Joseph H. Pierluissi, "Experimental Study of the Relationship Between Radiosonde Temperatures and Radiometric-Area Temperatures," ECOM-5599, August 1976.
36. Duncan, Louis D., "Stratospheric Wind Shear Computed from Satellite Thermal Sounder Measurements," ECOM-5800, September 1976.
37. Taylor, F., P. Mohan, P. Joseph and T. Pries, "An All Digital Automated Wind Measurement System," ECOM-5801, September 1976.
38. Bruce, Charles, "Development of Spectrophones for CW and Pulsed Radiation Sources," ECOM-5802, September 1976.
39. Duncan, Louis D., and Mary Ann Seagraves, "Another Method for Estimating Clear Column Radiances," ECOM-5803, October 1976.
40. Blanco, Abel J., and Larry E. Taylor, "Artillery Meteorological Analysis of Project Pass," ECOM-5804, October 1976.
41. Miller, Walter, and Bernard Engebos, "A Mathematical Structure for Refinement of Sound Ranging Estimates," ECOM-5805, November, 1976.
42. Gillespie, James B., and James D. Lindberg, "A Method to Obtain Diffuse Reflectance Measurements from 1.0 to 3.0 μm Using a Cary 171 Spectrophotometer," ECOM-5806, November 1976.
43. Rubio, Roberto, and Robert O. Olsen, "A Study of the Effects of Temperature Variations on Radio Wave Absorption," ECOM-5807, November 1976.
44. Ballard, Harold N., "Temperature Measurements in the Stratosphere from Balloon-Borne Instrument Platforms, 1968-1975," ECOM-5808, December 1976.
45. Monahan, H.H., "An Approach to the Short-Range Prediction of Early Morning Radiation Fog," ECOM-5809, January 1977.
46. Engebos, Bernard Francis, "Introduction to Multiple State Multiple Action Decision Theory and Its Relation to Mixing Structures," ECOM-5810, January 1977.
47. Low, Richard D.H., "Effects of Cloud Particles on Remote Sensing from Space in the 10-Micrometer Infrared Region," ECOM-5811, January 1977.
48. Bonner, Robert S., and R. Newton, "Application of the AN/GVS-5 Laser Rangefinder to Cloud Base Height Measurements," ECOM-5812, February 1977.
49. Rubio, Roberto, "Lidar Detection of Subvisible Reentry Vehicle Erosive Atmospheric Material," ECOM-5813, March 1977.
50. Low, Richard D.H., and J.D. Horn, "Mesoscale Determination of Cloud-Top Height: Problems and Solutions," ECOM-5814, March 1977.

51. Duncan, Louis D., and Mary Ann Seagraves, "Evaluation of the NOAA-4 VTPR Thermal Winds for Nuclear Fallout Predictions," ECOM-5815, March 1977.
52. Randhawa, Jagir S., M. Izquierdo, Carlos McDonald and Dan Salpeter, "Stratospheric Ozone Density as Measured by a Chemiluminescent Sensor During the Stratcom VI-A Flight," ECOM-5816, April 1977.
53. Rubio, Roberto, and Mike Izquierdo, "Measurements of Net Atmospheric Irradiance in the 0.7- to 2.8-Micrometer Infrared Region," ECOM-5817, May 1977.
54. Ballard, Harold N., Jose M. Serna, and Frank P. Hudson Consultant for Chemical Kinetics, "Calculation of Selected Atmospheric Composition Parameters for the Mid-Latitude, September Stratosphere," ECOM-5818, May 1977.
55. Mitchell, J.D., R.S. Sagar, and R.O. Olsen, "Positive Ions in the Middle Atmosphere During Sunrise Conditions," ECOM-5819, May 1977.
56. White, Kenneth O., Wendell R. Watkins, Stuart A. Schleutener, and Ronald L. Johnson, "Solid-State Laser Wavelength Identification Using a Reference Absorber," ECOM-5820, June 1977.
57. Watkins, Wendell R., and Richard G. Dixon, "Automation of Long-Path Absorption Cell Measurements," ECOM-5821, June 1977.
58. Taylor, S.E., J.M. Davis, and J.B. Mason, "Analysis of Observed Soil Skin Moisture Effects on Reflectance," ECOM-5822, June 1977.
59. Duncan, Louis D. and Mary Ann Seagraves, "Fallout Predictions Computed from Satellite Derived Winds," ECOM-5823, June 1977.
60. Snider, D.E., D.G. Murcray, F.H. Murcray, and W.J. Williams, "Investigation of High-Altitude Enhanced Infrared Background Emissions" (U), SECRET, ECOM-5824, June 1977.
61. Dubbin, Marvin H. and Dennis Hall, "Synchronous Meteorological Satellite Direct Readout Ground System Digital Video Electronics," ECOM-5825, June 1977.
62. Miller, W., and B. Engebos, "A Preliminary Analysis of Two Sound Ranging Algorithms," ECOM-5826, July 1977.
63. Kennedy, Bruce W., and James K. Luers, "Ballistic Sphere Techniques for Measuring Atmospheric Parameters," ECOM-5827, July 1977.
64. Duncan, Louis D., "Zenith Angle Variation of Satellite Thermal Sounder Measurements," ECOM-5828, August 1977.
65. Hansen, Frank V., "The Critical Richardson Number," ECOM-5829, September 1977.
66. Ballard, Harold N., and Frank P. Hudson (Compilers), "Stratospheric Composition Balloon-Borne Experiment," ECOM-5830, October 1977.
67. Barr, William C., and Arnold C. Peterson, "Wind Measuring Accuracy Test of Meteorological Systems," ECOM-5831, November 1977.
68. Ethridge, G.A. and F.V. Hansen, "Atmospheric Diffusion: Similarity Theory and Empirical Derivations for Use in Boundary Layer Diffusion Problems," ECOM-5832, November 1977.
69. Low, Richard D.H., "The Internal Cloud Radiation Field and a Technique for Determining Cloud Blackness," ECOM-5833, December 1977.
70. Watkins, Wendell R., Kenneth O. White, Charles W. Bruce, Donald L. Walters, and James D. Lindberg, "Measurements Required for Prediction of High Energy Laser Transmission," ECOM-5834, December 1977.
71. Rubio, Robert, "Investigation of Abrupt Decreases in Atmospherically Backscattered Laser Energy," ECOM-5835, December 1977.
72. Monahan, H.H. and R.M. Cionco, "An Interpretative Review of Existing Capabilities for Measuring and Forecasting Selected Weather Variables (Emphasizing Remote Means)," ASL-TR-0001, January 1978.
73. Heaps, Melvin G., "The 1979 Solar Eclipse and Validation of D-Region Models," ASL-TR-0002, March 1978.

74. Jennings, S.G., and J.B. Gillespie, "M.I.E. Theory Sensitivity Studies - The Effects of Aerosol Complex Refractive Index and Size Distribution Variations on Extinction and Absorption Coefficients Part II: Analysis of the Computational Results," ASL-TR-0003, March 1978.
75. White, Kenneth O. et al, "Water Vapor Continuum Absorption in the 3.5 μ m to 4.0 μ m Region," ASL-TR-0004, March 1978.
76. Olsen, Robert O., and Bruce W. Kennedy, "ABRES Pretest Atmospheric Measurements," ASL-TR-0005, April 1978.
77. Ballard, Harold N., Jose M. Serna, and Frank P. Hudson, "Calculation of Atmospheric Composition in the High Latitude September Stratosphere," ASL-TR-0006, May 1978.
78. Watkins, Wendell R. et al, "Water Vapor Absorption Coefficients at HF Laser Wavelengths," ASL-TR-0007, May 1978.
79. Hansen, Frank V., "The Growth and Prediction of Nocturnal Inversions," ASL-TR-0008, May 1978.
80. Samuel, Christine, Charles Bruce, and Ralph Brewer, "Spectrophone Analysis of Gas Samples Obtained at Field Site," ASL-TR-0009, June 1978.
81. Pinnick, R.G. et al., "Vertical Structure in Atmospheric Fog and Haze and its Effects on IR Extinction," ASL-TR-0010, July 1978.
82. Low, Richard D.H., Louis D. Duncan, and Richard B. Gomez, "The Microphysical Basis of Fog Optical Characterization," ASL-TR-0011, August 1978.
83. Heaps, Melvin G., "The Effect of a Solar Proton Event on the Minor Neutral Constituents of the Summer Polar Mesosphere," ASL-TR-0012, August 1978.
84. Mason, James B., "Light Attenuation in Falling Snow," ASL-TR-0013, August 1978.
85. Blanco, Abel J., "Long-Range Artillery Sound Ranging: "PASS" Meteorological Application," ASL-TR-0014, September 1978.
86. Heaps, M.G., and F.E. Niles, "Modeling the Ion Chemistry of the D-Region: A case Study Based Upon the 1966 Total Solar Eclipse," ASL-TR-0015, September 1978.
87. Jennings, S.G., and R.G. Pinnick, "Effects of Particulate Complex Refractive Index and Particle Size Distribution Variations on Atmospheric Extinction and Absorption for Visible Through Middle-Infrared Wavelengths," ASL-TR-0016, September 1978.
88. Watkins, Wendell R., Kenneth O. White, Lanny R. Bower, and Brian Z. Sojka, "Pressure Dependence of the Water Vapor Continuum Absorption in the 3.5- to 4.0-Micrometer Region," ASL-TR-0017, September 1978.
89. Miller, W.B., and B.F. Engebos, "Behavior of Four Sound Ranging Techniques in an Idealized Physical Environment," ASL-TR-0018, September 1978.
90. Gomez, Richard G., "Effectiveness Studies of the CBU-88/B Bomb, Cluster, Smoke Weapon" (U), CONFIDENTIAL ASL-TR-0019, September 1978.
91. Miller, August, Richard C. Shirkey, and Mary Ann Seagraves, "Calculation of Thermal Emission from Aerosols Using the Doubling Technique," ASL-TR-0020, November, 1978.
92. Lindberg, James D. et al., "Measured Effects of Battlefield Dust and Smoke on Visible, Infrared, and Millimeter Wavelengths Propagation: A Preliminary Report on Dusty Infrared Test-I (DIRT-I)," ASL-TR-0021, January 1979.
93. Kennedy, Bruce W., Arthur Kinghorn, and B.R. Hixon, "Engineering Flight Tests of Range Meteorological Sounding System Radiosonde," ASL-TR-0022, February 1979.
94. Rubio, Roberto, and Don Hoock, "Microwave Effective Earth Radius Factor Variability at Wiesbaden and Balboa," ASL-TR-0023, February 1979.
95. Low, Richard D.H., "A Theoretical Investigation of Cloud/Fog Optical Properties and Their Spectral Correlations," ASL-TR-0024, February 1979.

96. Pinnick, R.G., and H.J. Auvermann, "Response Characteristics of Knollenberg Light-Scattering Aerosol Counters," ASL-TR-0025, February 1979.
97. Heaps, Melvin G., Robert O. Olsen, and Warren W. Berning, "Solar Eclipse 1979, Atmospheric Sciences Laboratory Program Overview," ASL-TR-0026 February 1979.
98. Blanco, Abel J., "Long-Range Artillery Sound Ranging: 'PASS' GR-8 Sound Ranging Data," ASL-TR-0027, March 1979.
99. Kennedy, Bruce W., and Jose M. Serna, "Meteorological Rocket Network System Reliability," ASL-TR-0028, March 1979.
100. Swingle, Donald M., "Effects of Arrival Time Errors in Weighted Range Equation Solutions for Linear Base Sound Ranging," ASL-TR-0029, April 1979.
101. Umstead, Robert K., Ricardo Pena, and Frank V. Hansen, "KWIK: An Algorithm for Calculating Munition Expenditures for Smoke Screening/Obscuration in Tactical Situations," ASL-TR-0030, April 1979.
102. D'Arcy, Edward M., "Accuracy Validation of the Modified Nike Hercules Radar," ASL-TR-0031, May 1979.
103. Rodriguez, Ruben, "Evaluation of the Passive Remote Crosswind Sensor," ASL-TR-0032, May 1979.
104. Barber, T.L., and R. Rodriguez, "Transit Time Lidar Measurement of Near-Surface Winds in the Atmosphere," ASL-TR-0033, May 1979.
105. Low, Richard D.H., Louis D. Duncan, and Y.Y. Roger R. Hsiao, "Microphysical and Optical Properties of California Coastal Fogs at Fort Ord," ASL-TR-0034, June 1979.
106. Rodriguez, Ruben, and William J. Vechione, "Evaluation of the Saturation Resistant Crosswind Sensor," ASL-TR-0035, July 1979.
107. Ohmstede, William D., "The Dynamics of Material Layers," ASL-TR-0036, July 1979.
108. Pinnick, R.G., S.G. Jennings, Petr Chylek, and H.J. Auvermann "Relationships between IR Extinction, Absorption, and Liquid Water Content of Fogs," ASL-TR-0037, August 1979.
109. Rodriguez, Ruben, and William J. Vechione, "Performance Evaluation of the Optical Crosswind Profiler," ASL-TR-0038, August 1979.
110. Miers, Bruce T., "Precipitation Estimation Using Satellite Data" ASL-TR-0039, September 1979.
111. Dickson, David H., and Charles M. Sonnenschein, "Helicopter Remote Wind Sensor System Description," ASL-TR-0040, September 1979.
112. Heaps, Melvin, G., and Joseph M. Heimerl, "Validation of the Dairchem Code, I: Quiet Midlatitude Conditions," ASL-TR-0041, September 1979.
113. Bonner, Robert S., and William J. Lentz, "The Visioceilometer: A Portable Cloud Height and Visibility Indicator," ASL-TR-0042, October 1979.
114. Cohn, Stephen L., "The Role of Atmospheric Sulfates in Battlefield Obscurations," ASL-TR-0043, October 1979.
115. Fawbush, E.J. et al, "Characterization of Atmospheric Conditions at the High Energy Laser System Test Facility (HELSTF), White Sands Missile Range, New Mexico, Part I, 24 March to 8 April 1977," ASL-TR-0044, November 1979
116. Barber, Ted L., "Short-Time Mass Variation in Natural Atmospheric Dust," ASL-TR-0045, November 1979
117. Low, Richard D.H., "Fog Evolution in the Visible and Infrared Spectral Regions and its Meaning in Optical Modeling," ASL-TR-0046, December 1979
118. Duncan, Louis D. et al, "The Electro-Optical Systems Atmospheric Effects Library, Volume I: Technical Documentation, ASL-TR-0047, December 1979.
119. Shirkey, R. C. et al, "Interim E-O SAEL, Volume II, Users Manual," ASL-TR-0048, December 1979.
120. Kobayashi, H.K., "Atmospheric Effects on Millimeter Radio Waves," ASL-TR-0049, January 1980.
121. Seagraves, Mary Ann and Duncan, Louis D., "An Analysis of Transmittances Measured Through Battlefield Dust Clouds," ASL-TR-0050, February, 1980.

122. Dickson, David H., and Jon E. Ottesen, "Helicopter Remote Wind Sensor Flight Test," ASL-TR-0051, February 1980.
123. Pinnick, R. G., and S. G. Jennings, "Relationships Between Radiative Properties and Mass Content of Phosphoric Acid, HC, Petroleum Oil, and Sulfuric Acid Military Smokes," ASL-TR-0052, April 1980.
124. Hinds, B. D., and J. B. Gillespie, "Optical Characterization of Atmospheric Particulates on San Nicolas Island, California," ASL-TR-0053, April 1980.
125. Miers, Bruce T., "Precipitation Estimation for Military Hydrology," ASL-TR-0054, April 1980.
126. Sternmark, Ernest B., "Objective Quality Control of Artillery Computer Meteorological Messages," ASL-TR-0055, April 1980.
127. Duncan, Louis D., and Richard D. H. Low, "Bimodal Size Distribution Models for Fogs at Meppen, Germany," ASL-TR-0056, April 1980.